Statistical Tools for Fitting Models of the Population Consequences of Acoustic Disturbance to Data from Marine Mammal Populations (PCAD Tools II)

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LONG-TERM GOALS

Our goal is to build an ecological modeling framework that facilitates understanding of the way in which at-sea condition and health of various species of marine mammals changes over time. This project will develop statistical tools to allow mathematical models of the population consequences of acoustic disturbance to be fitted to data from marine mammal populations. We will work closely with Phase II of the ONR PCAD Working Group, and will provide statistical support to that group.

OBJECTIVES

Our scientific objectives are to build a statistical framework for understanding the way in which at-sea health varies over time for (initially) three species of marine mammals: southern and northern elephant seals, and northern right whales.

For elephant seals our objective is to describe – both for elephant seal biologists, and ecologists working on body condition – the steps necessary to fit the model from Schick et al. (2013b) to data. This will take the form of a manuscript that includes an appendix that describes how to fit the code to data and how to interpret results. In addition, we have fit the model to data from a set of post-breeding females for a PhD student in Mark Hindell's lab.

For right whales, our primary objective is to continually refine the model that provides spatially and temporally explicit estimates of individual health, movement, and survival Schick et al. (2013a). We have three goals for this research at present: 1) to scale understanding of health changes from the individual through the sub-population level, and finally to the level of the entire right whale population; 2) to intersect the temporal extent data on known entanglements with individual health estimates to better understand how health changes during entanglement events as a function of entanglement severity; and 3) to develop a draft report card of the health of the right whale population. Throughout each of these objectives, we have relied on R to not only fit the model to data, but also to develop reproducible documents, and interactive graphical visualisations.

A secondary objective within the right whale project is to use the model and expert opinion to refine our understanding of movements of individual right whales into and out of the mid-Atlantic region.

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APPROACH

During our PCAD meeting in AUTEC in 2011, Mark Hindell asked Clark and Schick if we would develop a document highlighting how the lipids model Schick et al. (2013b) could be fit to data. The goal is to allow biologists to work with the model themselves. Last year, one of Hindell's graduate students, Malcom O'Toole, contacted Schick to see about fitting the model to post-breeding females from Macquarie and Kerguelen Islands. Schick fit the model to these data; the results from this work comprise one chapter of O'Toole's PhD thesis, and is being developed into a manuscript. While fitting the model, Schick wrote a knitr document for O'Toole describing how the model works, how to fit it to data, and how to interpret the results. Schick then turned this knitr document into an appendix of a software note type of manuscript, which has been submitted twice this year. Now the manuscript will be submitted as part of the Proceedings of the Bio-logging conference at the end of September, 2014.

Schick has worked closely with colleagues from the New England Aquarium (hereafter NEAq) to refine the right whale model, and to use its output to understand health changes at multiple levels (i.e. individual, sub-population, and population). (n.b. – much of these results will be highlighted in the report for award N000141210389.) In addition, we have used model output together with known entanglement events to understand how individual health changes as a function of one particular disturbance – entanglement with fishing gear. Finally, we have used model output in three ways to develop an intial report card for right whale health that will be presented annually at each Right Whale Consortium (RWC) meeting. These three ways include: 1) using individual survival estimates to tally the number of whales estimated to be alive, as well as the number of whales estimated to have died in the present year; 2) deliberately depauperating the visual health parameter data to underscore the importance of these data on our understanding of health and survival; and 3) documenting a model – update – model cycle with an additional year's worth of data to understand how estimates of survival change.

We (Schick, Erica Fleishman, and Philip Hamilton) conducted a two-part expert elicitation in November of 2013, with the second part comprised of a face-to-face workshop that included the polled experts. Initial results were presented at the RWC meeting in November, 2013.

WORK COMPLETED

In the past year, our work has focused along two primary avenues: 1) developing and submitting for publication a manuscript that documents the Gibbs sampler and computer code necessary to fit the lipids gain model to elephant seal data, and 2) continual refinements and improvements to the right whale model. Within the second line of work, most of the research has been aimed at further understanding of right whale health at the individual, sub-population, and population levels. This work is in conjunction with collaborators from the NEAq – primarily with Roz Rolland. In addition to the work with Rolland, we have worked closely with Amy Knowlton from NEAq to intersect model output with information on entanglement in order to assess the effects of this type of disturbance on right whale health.

As outlined above, much of the model refinement has proceeded with the benefit of an iterative collaboration between Schick and colleagues at NEAq. Accordingly, Schick has developed a series of summary writeups that include R code, tabular and graphical results, and textual explanation. Once written, these documents are shared with NEAq, who review them, and provide comments for refinements of the model. The refinements are then made, and the documents updated. This cycle has greatly facilitated interaction between St Andrews and NEAq.

Schick has begun drafting a manuscript that highlights the use of these tools as well as the use of interactive graphics to facilitate model understanding as well as model enhancement. These results will be presented at the RWC meeting this fall, and submitted before the end of the calendar year.

We held a two part elicitation ahead of the RWC meeting last November, and have integrated results into the modeling workflow. Results from the first round of modeling highlighted the qualitative difference between the questions that we asked the experts during the elicitation, and the way in which Hamilton originally developed the priors for movement. This difference effectively means the two sources of information are incoherent. Accordingly the manuscript will focus more on applying elicitation techniques within ecology and conservation as opposed to new insights into right whale movements in the mid-Atlantic.

The full list of publications is given at the end of this report. Here is a list of presentations given in the past year.

- Schick, Annual Right Whale Consortium Meeting in New Bedford, MA November 6th-7th, 2013 (*Talk*)
- Schick, R.S. Hidden Markov Model Symposium, The Boyd Orr Centre for Population and Ecosystem Health, University of Glasgow, Scotland. February 13th, 2014 **(***Invited Talk***)**
- Schick, R.S. International Marine Conservation Congress, Glasgow, Scotland. August 14th–19th, 2014 **(***Invited Talk***)**
- Schick et al. The 5th Bio-logging Science Symposium, Strasbourg, France. September 22nd-26th, 2014 (*Poster)*

RESULTS

From the individual estimates of health we can assemble a holistic understanding of population level health in right whales. To create this population average, we combined health estimates from adult males, young and old juveniles – of both genders (Figure 1). We excluded adult females in order to separate the annual reproductive cycle from our understanding of health. We used this population average to place fluctuations in individual health in better context (Figure 2). For example, EGNo 1245 had two periods of worse than average health in 1985, and the late 1990's (Figure 2). Following this period of poor health, she recovered well and went on to have three more calves. In contrast EGNo 1333 had either average or below average prior to his death in 1998 (Figure 3).

We quantified average health for different stage classes of the population, e.g. lactating females, older juveniles, etc. This has identified those stage classes whose health is notably different from the entire population, i.e. pregnant females (Figure 4). Interestingly while average population health was poor from 1997-1999 (Figure 1), available females appeared to be recovering more quickly.

Lastly, results from one of the 14 elicitation questions indicate a high percentage (~ 50%) of adult male right whales remaining in the mid-Atlantic from December to January (Figure 5). These are much higher than the current priors used in the model (generated by Philip Hamilton, NEAq).

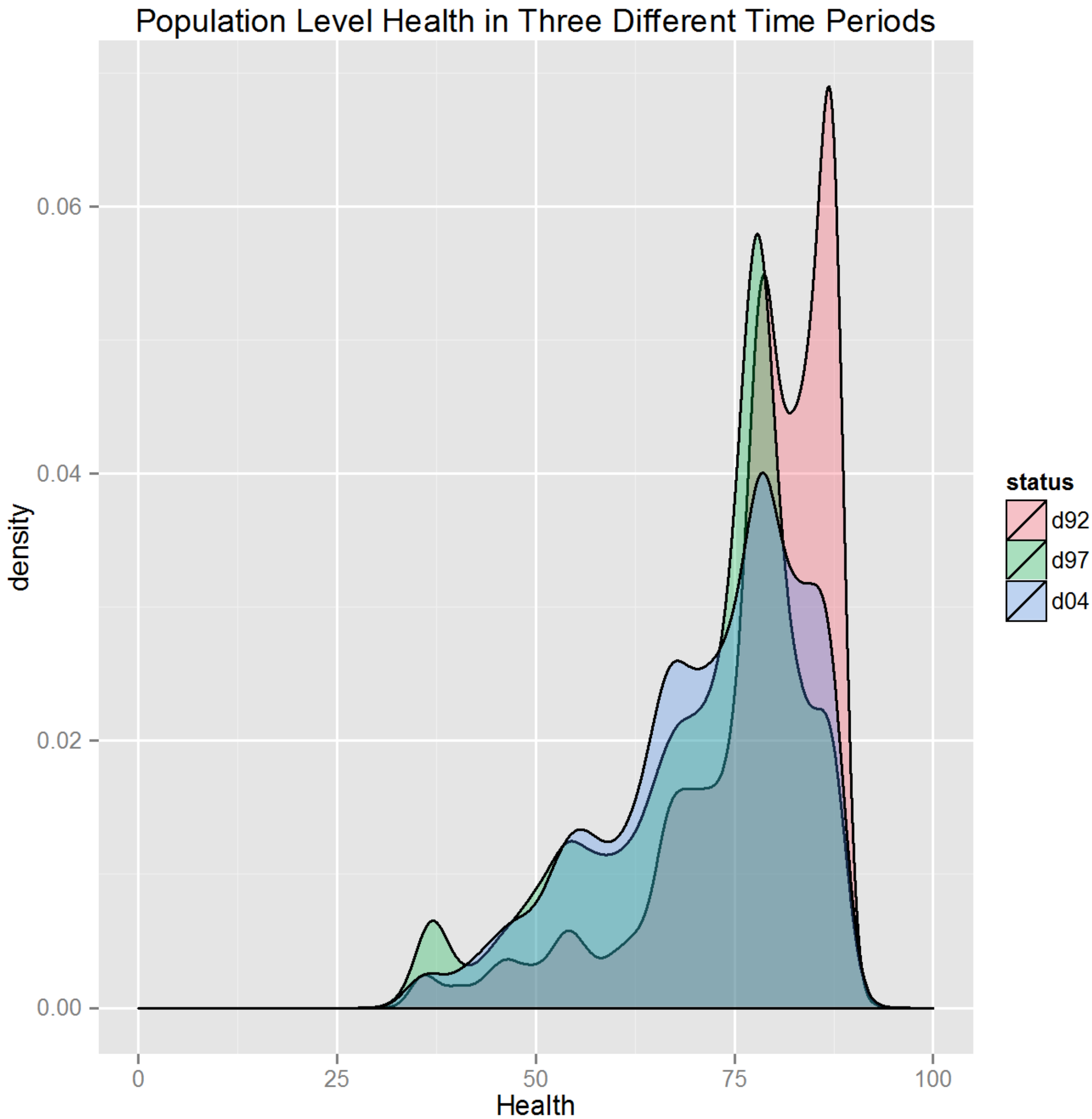

Figure 1. Density plot of population health in three different periods: 1992-94, 1997-99, 2004-06. Health was poorest in the late-1990's period, which corresponded to a period of very low calving in the entire population.

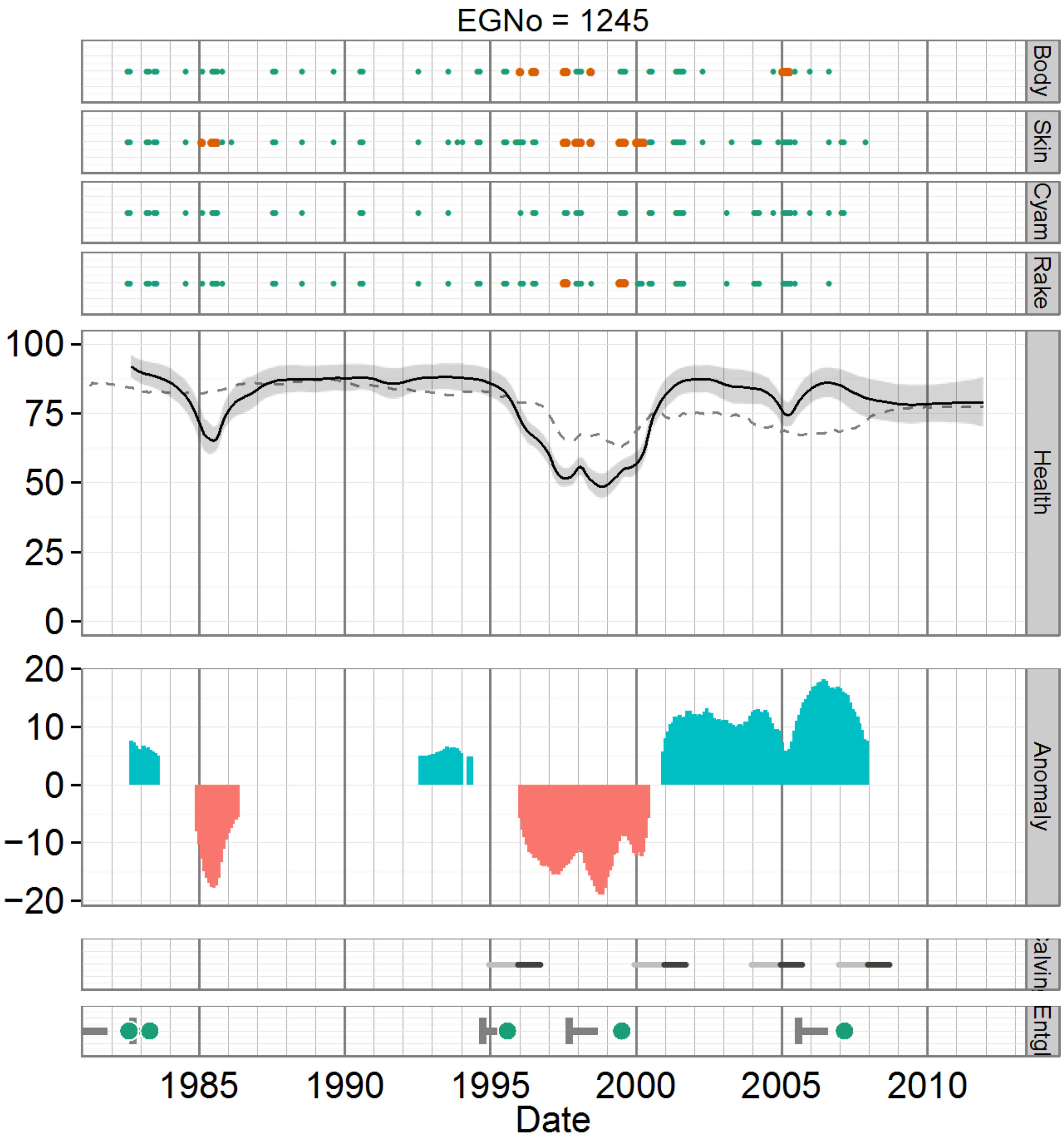

Figure 2. Health estimates (middle panel labeled "Health") for right whale # EGNo 1245, with uncertainty, represented as solid and shaded grey area, respectively. Dashed line represents population health. "Anomaly" panel depicts deviations of individual health from population health. Data observations are shown (top panels) for body fat, skin condition, presence of cyamids, and the presence of rake marks. Gestational status (grey = pregnancy year; black = calving year), and entanglement status are not included as data in the model, but are shown in bottom panels. Observations where the animal is observed in poorer condition are shown with orange dots. Following a period of below average health in the late 1990's, 1245 was much healthier than average for much of the early 2000's. This animal is presumed alive.

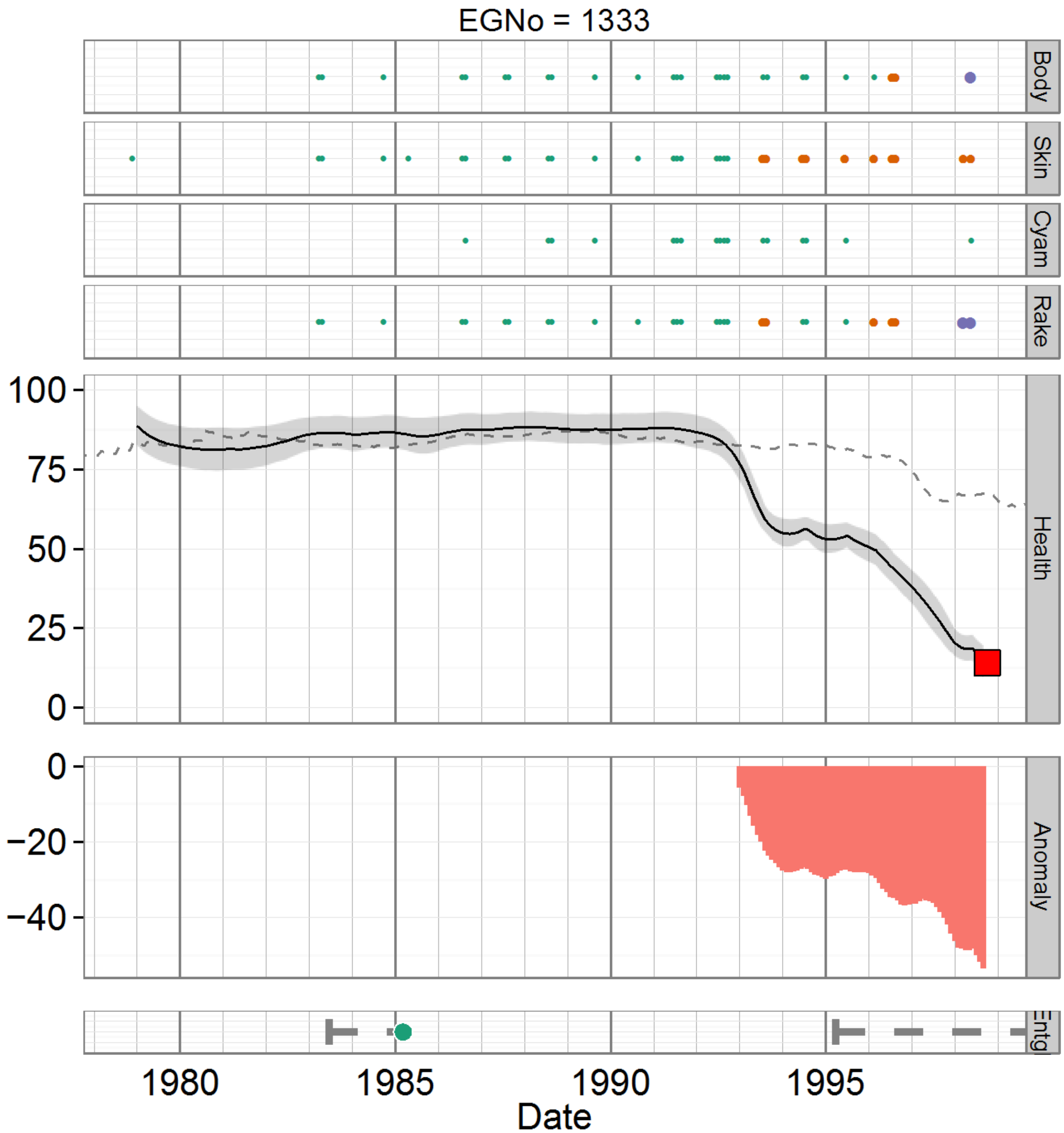

Figure 3. Health estimates (middle panel labeled "Health") for right whale # EGNo 1333, with uncertainty, represented as solid and shaded grey area, respectively. Dashed line represents population health. "Anomaly" panel depicts deviations of individual health from population health. Data observations are shown (top panels) for body fat, skin condition, presence of cyamids, and the presence of rake marks. Entanglement status is not included as data in the model, but events are shown in the bottom panel. Observations where the animal is observed in poorer condition are shown with orange and purple dots. A period of below average health started in 1993 and steadily worsened until the animal's death 1998.

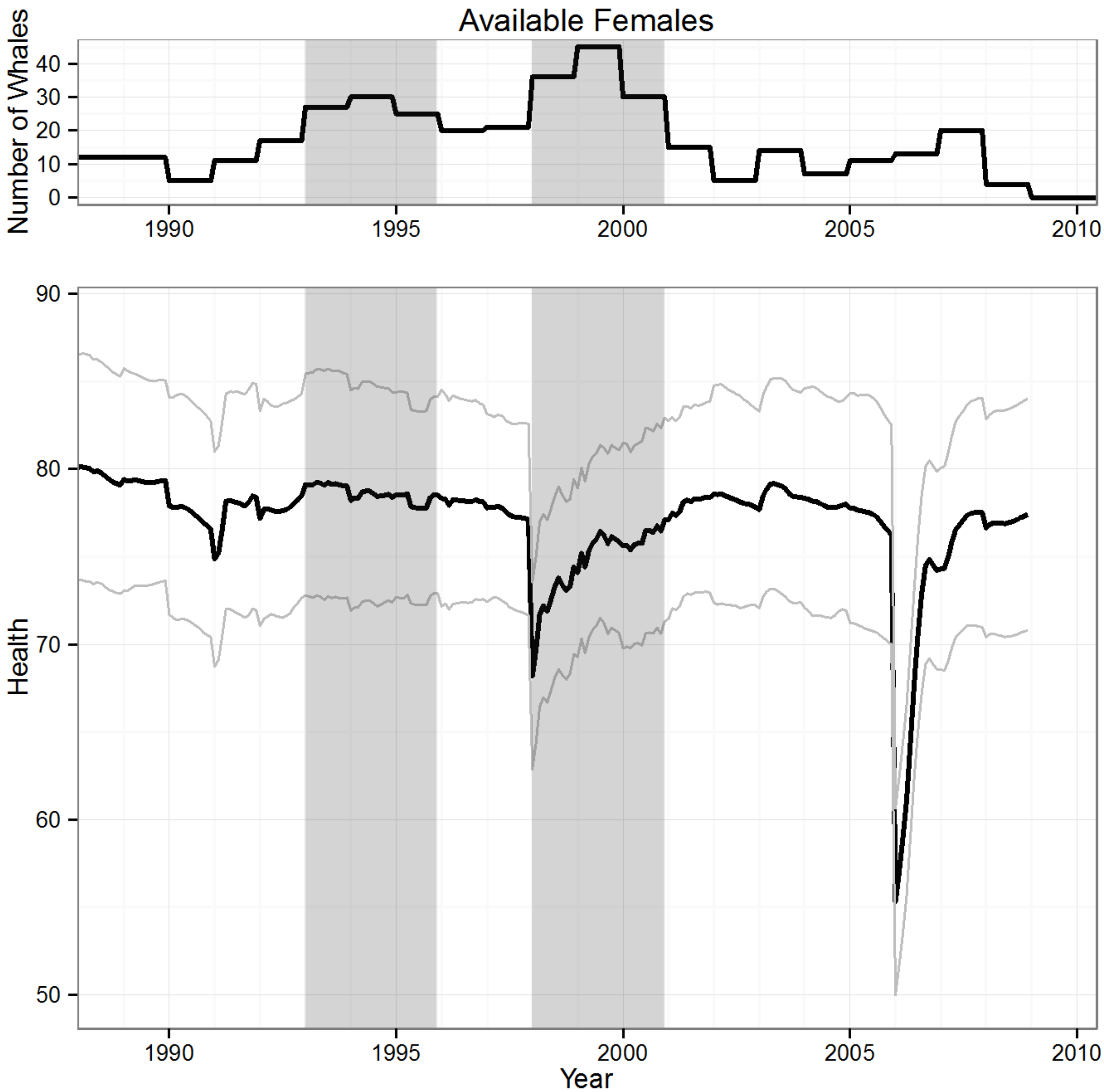

Figure 4. Estimates of health in female right whales that are available to become pregnant, i.e. they are one or more years past their resting year – the year following calving (lower panel); number of females in this sub-population class depicted in top panel. The number of females in this class increased in the late 1990's, and their health was considerably lower than earlier periods. As compared to the population average (Figure 2), there is evidence that health of these females increased more rapidly.

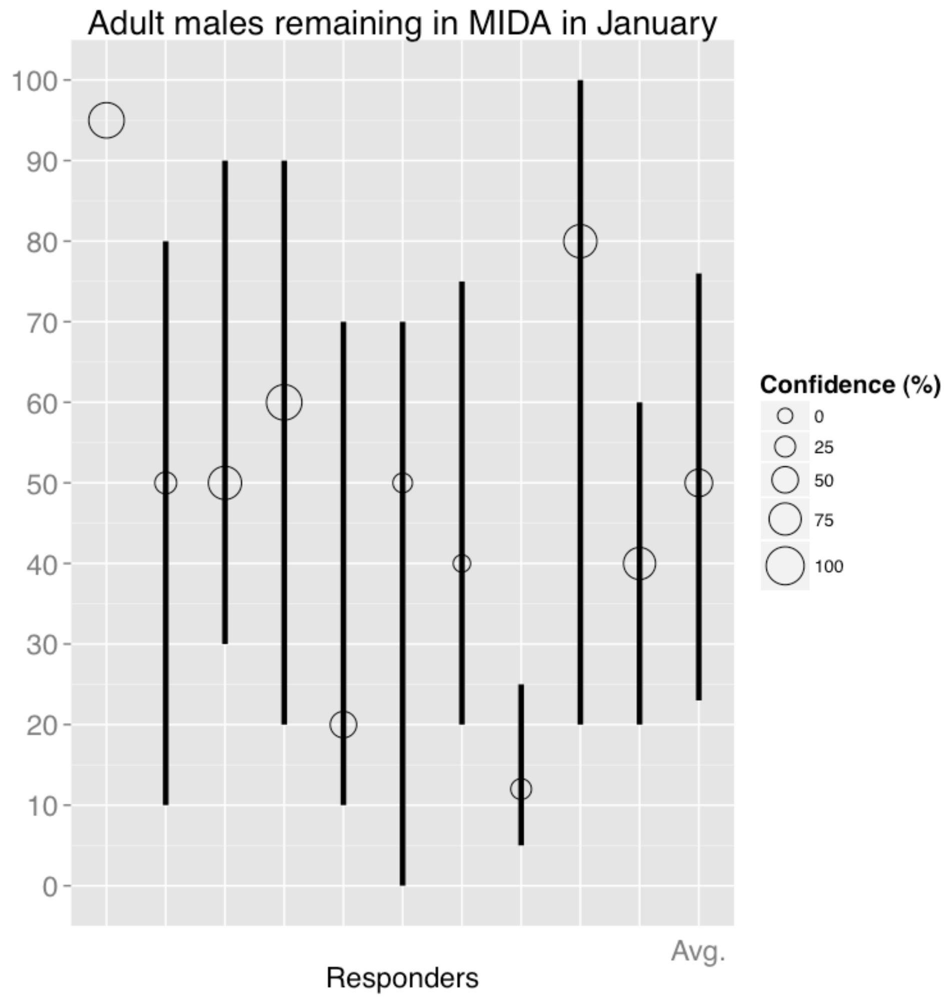

Figure 5. Summary plot of answers from one question asked during an expert elicitation exercise in November 2013. The question asked of 100 male right whales in the mid-Atlantic in December, how many would remain in the mid-Atlantic in January. Ten experts were polled, and asked to give a low, high, median number, as well as a confidence level about their answer. Circles are drawn at the median level; size of circle corresponds to confidence. Note that expert 1 had the same answers for the low, high, and median number of whales remaining in the area.

IMPACT/APPLICATIONS

The modeling efforts described here also have broad relevance in animal ecology. The elephant seal analysis provides insight into the detailed aspects of the physiological status of individual animals at fine spatial and temporal scales. Though our analysis takes advantage of a behavior that is unique to elephant seals, by developing and documenting the Gibbs sampler/code manuscript, we hope to provide a way for all biologists working on body condition and movement to estimate and highlight critical spatiotemporal patterns of body condition gain and loss. For example, as part of a MASTS research fellowship granted to Schick, we will be applying a version of this framework to look at at-sea changes in body condition in harbour seals in relation to sources of acoustic disturbance through the construction of offshore wind farms in the Moray Firth, Scotland.

The right whale analysis provides a critically important baseline view of right whale health across a large variety of background environmental conditions over the past 30 years. This baseline can be used to understand how future disturbance – anthropogenic, or naturally occuring – may impact population health. We can use the population level baseline (Figure 1) to better place individual health estimates in better context (Figures 2 & 3). For example, we know the whole population health crashed in the late 1990's, but some individuals and sub-population categories did better than others (Figure 4). By comparing individuals to the whole population, we can further investigate how certain disturbances will impact different groups within the species.

The relationship between a disturbance, an animal's health and ultimately its survival is the foundation of PCAD. The understanding of these links is critical for the Navy as it continues to assess what impact its activities may have on the health and survival of marine mammals.

RELATED PROJECTS

This project is closely related to two other ONR awards: N000141210389 to Scott Kraus (New England Aquarium), and N000141210274 to Erica Fleishman (UC-Davis).

PUBLICATIONS

Costa, D. P., L. Schwarz, P. W. Robinson, R. S. Schick, P. A. Morris, R. S. Condit, D. E. Crocker, and A. M. Kilpatrick. 2014. A Bioenergetics Approach to Understanding the Population Consequences of Disturbance: Elephant seals as a Model System. *in* A. N. Popper and A. Hawkins, editors. Effects of Noise on Aquatic Life II. Springer. [2014]

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Schick, R. S., L. F. New, L. Thomas, D. P. Costa, M. A. Hindell, C. R. McMahon, P. W. Robinson, S. E. Simmons, M. Thums, J. Harwood, and J. S. Clark. 2013b. Estimating resource acquisition and at-sea body condition of a marine predator. Journal of Animal Ecology 82:1300–1315.